CONSTRUCTED WETLANDS FOR CONFINED SWINE WASTEWATER TREATMENT

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Currently, most animal production enterprises apply both solid and liquid waste to forage and crop land. Land application of waste becomes a problem when more manure nitrogen is produced than crop or forage land can assimilate (Barker and Zublena, 1995). Consequently, public concern and changing environmental regulations are stressing the need for alternative treatment methods that require less land area for manure treatment. These alternative methods include constructed wetlands (Humenik *et al.*, 1995).

Even though wetlands have produced some impressive treatment results (Hammer, 1989), a better understanding of their function and optimal placement in a livestock waste treatment system is necessary (Humenik *et al.*, 1998). Our research had the objective to assess the ability of wetlands to remove nitrogen and thereby decrease the required land application area.

MATERIALS AND METHODS

Constructed Wetland Site

Site. A 2,600-pig nursery (average weight = 13 kg) in Duplin Co., NC, USA, that used a flushing system to recycle liquid from a single-stage lagoon. Typically, the lagoon liquid contained 365 mg L^{-1} TKN (> 95% NH_3-N), 93 mg L^{-1} TP, and 740 mg L^{-1} COD.

Wetlands. Six 3.6- by 33.5-m free-surface-flow wetland cells were constructed adjacent to the treatment lagoon in 1992. Cell bottoms were graded to a 0.2% slope and sealed by a compacted clay liner. Wetland cells were planted either to a polyculture of natural wetland plants or to water-tolerant agronomic plants. Three systems were evaluated; each consisted of two cells connected in series.

Plant Materials and Monitoring

Plants. System 1 contained rush (*Juncus effusus*) and bulrush (*Scirpus americanus*, *Scirpus cyperinus* and *Scirpus validus*); system 2 contained bur-reed (*Sparganium americanum*) and cattails (*Typha angustifolia* and *Typha latifolia*). System 3 consisted of one cell that contained soybean (*Glycine max*) grown in saturated-soil culture connected to a second cell that contained flooded rice (*Oryza sativa*).

Monitoring. Inflow and outflow were measured by use of V-notch weirs with ultra-sonic depth detectors and tipping bucket flowmeters. Water samples for N analysis were obtained using automated samplers. Water samplers combined samples into three-day composites.

Nitrogen Application Rates and Laboratory Analyses

Wastewater was initially diluted with fresh water and applied at a nitrogen rate of 3 kg ha^{-1} day^{-1}. The dilution rates were decreased when higher N loading rates were applied in subsequent years. The N loading rates were increased to 8, 15, and 25 kg ha^{-1} day^{-1} in the subsequent three years. Wastewater was not applied to the soybean and rice cells after grain maturity.

Plant materials were oven-dried at 60°C to constant weight. Plant material subsamples were ground and digested using a block digestion technique. Digestates were analyzed for N using a Technicon II Auto-Analyzer. Water samples were analyzed for NO_3+ NO_2-N, NH_3-N, and TKN according to U.S. EPA (1983) methods using a TRAACS 800 Auto-Analyzer. In water samples, total N = TKN + [NO_3+ NO_2-N].

Mass Balance

The nutrient mass balance was calculated for N by the product between the inflows and outflows and its respective nutrient concentrations. Since nutrients concentrations were considered negligible in precipitation and groundwater inflow or outflow were zero because of the clay liner, the mass balance closure is reduced to:

$$\frac{\Delta M}{\Delta t} = \frac{Si \times Ci - So \times Co}{A}$$

M = mass of N per unit area treated by the system; it includes the N in soil, plant and microbial biomass. It is also assumed that losses by denitrification and ammonia volatilization are included.
$\Delta M/\Delta t$ = change in mass of N wetland per unit time.
Si and So = surface inflow and outflow of wastewater per unit time.
Ci and Co = inflow and outflow N concentration.
A = wetland area.

RESULTS AND DISCUSSION

Plant Performance

Growth was good for wetland and agronomic plants (Table 1). Grain yields were moderate; average soybean and rice yields were 2,200 and 4,000 kg ha^{-1}, respectively. Although the > 170 N kg ha^{-1} yr^{-1} accumulated by plants would be significant for the nutrient balance of an agronomic system, it was a relatively small portion of the total N load to the wetlands.

TABLE 1. Mean Aerial Dry Matter Production and Nitrogen Accumulation by Wetland and Agronomic Plants (1993-1996).

Plants	Dry matter	N accumulation
	---------- kg/ha/yr ----------	
Rush/Bulrush	16,900	300
Cattails/Bur-reed	19,700	378
Soybean[a]	5,600	169
Rice	10,900	233

[a]Soybean and rice total dry matter production at harvest = grain + stalks.

Nitrogen Removal Efficiency

Nitrogen removal efficiency in the soybean-rice treatment was about 75% at loading rates between 3 and 8 kg ha^{-1} d^{-1}. However, the soybean-rice system had higher total N effluent concentrations than the natural wetland plant systems (Figure 1). At same loading rates, N removal efficiencies for the soybean-rice system were lower than the natural wetland plant systems.

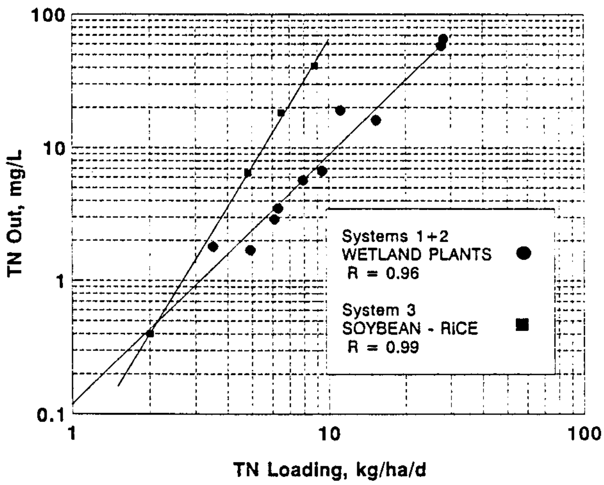

FIGURE 1. Relationship Between Mass Loadings and Effluent Concentrations. Data Points are the Means for Each Growth Season with Wetland Plants (April-October, 1993-1997) and Rice-Soybean (June-October, 1993-1996) Treatments.

The wetlands with natural plants showed great promise by removing > 80% of the applied N. During 1997, the removal rates with wetland plants did not decrease even though the application rate was 25 kg ha^{-1} d^{-1} (Table 2). At this rate and 300 application days, wetlands could remove > 5,000 kg ha^{-1} yr^{-1}. These high rates of nitrogen removal were likely due to microbial conversion of excess nitrogen in the wastewater to N gas via nitrification-denitrification. In a related study, Hunt *et al.* (1999) showed that these wetlands had prevalent anaerobic conditions and were nitrate limited. These conditions indicated that some direct loss of ammonia by volatilization cannot be disregarded. Consequently, alternative nitrification pre-treatments that would lower potential gaseous loss of ammonia and eliminate dilution with fresh water prior wetland treatment have also been investigated (Rice *et al.*, 1999). These alternative treatments are consistent with our view that improved wastewater treatment could be achieved by sequencing nitrification and wetland treatments.

TABLE 2. Mass Removal of N in Constructed Wetlands with Wetland Plants (June 1993-November 1997).

Nitrogen Load	System 1: Rush/bulrush	System 2: Cattails/bur-reed
kg/ha/day	Mass Removal, %[a]	
3	94	94
8	88	86
15	85	81
25	90	84

[a] % Mass Removal = % mass reduction of N in the effluent with respect to the nutrient mass inflow. Mass removals were estimated using treatment data obtained during both dormant and plant growth periods.

SUMMARY

The goals of our studies were to assess the ability of constructed wetlands to remove nitrogen and thereby prevent overloading of land application areas. Saturated-soil culture soybean and flooded rice produced modest grain yields while treating wastewater for removal of N. The wetlands with natural plants showed great promise by removing > 80% of the N at an application rate of 25 kg ha^{-1} d^{-1}. At this rate and 300 application days, wetlands could remove > 5,000 kg ha^{-1} yr^{-1} which is much higher than what cropland or forage land can remove on a yearly basis. We assumed that most of the N was microbially converted to N gas by nitrification-denitrification processes. However, additional investigations indicated that the wetlands were highly reducing and nitrate limited. Since ammonia is the prevalent form of N in these wetlands, some direct loss of N as ammonia gas cannot be disregarded. Additional research is being carried out to increase their N mass removal efficiency by nitrifying the effluent prior to wetland treatment. This pre-wetland treatment will eliminate wastewater dilution and lower gaseous loss of ammonia.

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